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Production of eco-friendly permeable brick from debris

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HIGHLIGHTS

- New permeable bricks were prepared by using all debris (dredged mud, waste glass, discarded porcelain).
- The affect factors including the content of aggregates, aggregate gradation, forming pressure, the ratios of MG as well as sintering temperature were investigated.
- The permeable brick's compressive strength is 33 MPa, permeability coefficient is 0.15 cm/s, and its leaching of heavy metals was in line with industry standard.

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ABSTRACT

In this study, eco-friendly high-performance permeable bricks were studied using three kinds of common debris (dredged mud, waste glass, discarded porcelain) as raw materials. The structure of permeable brick is composed of a large void connecting small pores, which achieves an optimal balance between water permeability and compressive strength. The large void is formed by the accumulation of discarded porcelain, and the small pores are produced by the combustion of organic matter in the dredged mud. The effects of aggregate gradation, aggregate content, weight ratios of dredged mud to waste glass, forming pressure and sintering temperature on porosity, permeability and compressive strength of the prepared permeable bricks were systematically investigated. With the optimal process conditions determined in the experiments (aggregate gradation = 2.675–3.530 mm, discarded porcelain = 70 wt%, ratio of dredged mud to glass powder = 3:1, forming pressure = 15 MPa, and sintering temperature = 1140 °C), the prepared permeable bricks have a high permeability (approximately 0.15 cm/s) and exhibit considerable compressive strength (approximately 33 MPa). The leaching of heavy metals was in line with industry standards.

1. Introduction

The concept of green ecology and energy conservation policies have been further promoted throughout the world. Researchers have focused on the concept of building a sponge city, which is the current advanced trend in urban construction in recent decades. To respond to this environmental philosophy, a permeable brick with a series of irreplaceable advantages was taken into our consideration and has attracted significant scientific attention in recent years. This permeable brick has the characteristics of mitigating the heat island effect, absorbing noise and adding groundwater, and its surface roughness could increase anti-skid performance to improve road safety [1]. An ordinary brick can guarantee a certain strength for buildings and facilities to satisfy the strength requirements of the built facility; however, it still suffers from a large challenge in effective water saving because its water permeability and penetration area decrease with increasing strength [1,2]. Based on this trait, various strategies have been developed to solve this problem for the last decade. The "wastes of materials" technology for producing permeable bricks was considered to be an effective and environmentally friendly method to improve water saving efficiency; meanwhile, its strength could be maintained or even increased. This technology has been shown to be successful in actual applications [3]. For example, Lin et al investigated the recovery of municipal waste incineration bottom ash and water treatment sludge for water permeable brick, which was applied as pavement material. The as-prepared brick can have a compressive strength of 26 MPa, a water absorption ratio of 2.78% and a permeability of 0.016 cm/s [3]. Yang et al showed that a prepared water permeable brick with 60% additive discarded ceramics has a compression strength of 49 MPa, a bending strength of 8 MPa and a permeation coefficient of 0.0312 cm/s [4]. The preparation of permeable bricks by coal angstroms and aluminum hydroxide showed that the permeability coefficients range from 1.37 cm/s to 1.55 cm/s, and the compressive strengths of the samples range between 31 and 34 MPa [5].

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The above series of studies used waste produced permeable bricks, which could solve the problems of ordinary bricks to some extent. Those samples could not achieve an increase in water permeability, strength and cost at the same time. In addition to having excellent water permeability, permeable brick is expected to have a certain level of mechanical performance. Based on these criteria, we did an extensive investigation and found that dredged mud could be adopted as a binder to replace clay, which is used in traditional bricks due to their similar chemical compositions. Discarded porcelains are suitable as aggregates, which have a promise of low costs and environmental benefits [4]. The use of glass, which is a non-biodegradable material, causes a problem for solid waste disposal. Significant amounts of glass could be consumed as high-temperature binders in the preparation of permeable brick, in which the quality requirement of glass is low [6,7]. The glass waste transforms to a high-temperature molten liquid phase, which will tightly connect the aggregate to improve the compressive strength of permeable bricks. In current practice, discarded porcelain and dredged mud are disposed of in the sea or backfilled in the ground without effective utilization. Those methods of disposal waste the associated resources, occupy vast areas of land and lead to potential environmental and safety problems, including but not limited to contamination of surface water, groundwater and soils [8]. Hence, we have chosen three sources of common debris (dredged mud, waste glass, discarded porcelain) as second-use recycling materials to obtain eco-friendly high-performance permeable bricks in which a balance can be achieved between water permeability, strength and production costs. Specifically, the permeability coefficient of the as-prepared permeable brick reached 0.15 cm/s and the compressive strength increased to 33 MPa, which is relatively favorable among other permeable bricks. Most importantly, this recipe requires a much lower expenditure than in previous reports [5]. In addition, its leaching of heavy metals was in line with industry standards.

The optimal performances of permeable brick (compressive strength, water permeability, porosity) were determined by adjusting the following factors, including the content of discarded porcelain, aggregate gradation, weight ratios of dredged mud to waste glass (MG ratios), forming pressure and sintering temperature. By altering the parameters of the permeable brick, this study obtained an optimal relationship between strength and water permeability. This is done, for instance, by increasing the grade or content of the discarded porcelain or by reducing the amount of the binder to increase the permeability. We have taken into account the possible presence of a small amount of heavy metals in the dredged mud, which may cause environmental problems during re-use. The dredged mud needs to be checked using a validation scheme upon second use, so we used a TCLP test to identify hazardous materials [6–10]. In this paper, we have also taken a deeper look into the inter-relationships among porosity, compressive strength and water permeability, which has a guiding significance needed for the mix design of permeable bricks. This paper studies the feasibility of utilizing debris (dredged mud, waste glass, discarded porcelain) to produce eco-friendly permeable bricks. This process would bring significant economic, environmental and social benefits in terms of groundwater conservation, fresh water savings, urban waterlogging prevention, and cost savings for drainage system construction and maintenance.

2. Experiment

2.1. Materials and preparation process

The raw materials of dredged mud (obtained from Guangzhou) and discarded porcelain (Foshan Oceanland Ceramics Company) were dehydrated through a series of operations. The waste glass used in this study was obtained from Lianyungang, Jiangsu (Fu Cai Mineral Products Co., Ltd). This company screened the waste glass into particle sizes between 0.131 and 0.154 mm.

All materials were homogenized and transferred in clean glass jars, capped with aluminum foil and kept in the dark at 4 °C until analysis. In addition, the chemical compositions (wt%) of these three raw materials were tested using X-ray Fluorescence (XRF), and the results are shown in Table 1. According to XRF analysis, the dredged mud consists of SiO_2 and Al_2O_3 as its major components, along with Fe_2O_3 as a minority constituent. The main components of discarded porcelain mud are SiO_2, Al_2O_3 and K_2O, and the main ingredients of waste glass are SiO_2, Na_2O, and CaO. All materials had a loss of ignition (LOI), which is likely associated with decomposition of carbonates and sulfates and with the burn-off of the organic matter that is usually adsorbed on this type of material [11].

The dredged mud was oven-dried at 105 °C for 24 h, and then crushed before being ball milled for 2 h in a ball mill machine. Before the dredged mud was used for subsequent sintering experiments, it was ground to break the agglomeration of the powder and sieved to an aggregate size of <0.546 mm. Similarly, discarded porcelain was ground and sieved to different aggregate size portions of 0.854–1.237 mm, 1.237–2.675 mm and 2.675–3.530 mm. Here, the shape of the aggregates broken by the crusher is needle-like or flaky with uneven edges, which would lead to poor water permeability [2]. Thus, these aggregates require a ball mill process in order to obtain a spherical morphology with rounded edges.

The mixtures (dredged mud, waste glass, discarded porcelain) were prepared according to the ratio of the raw materials in Table 2. The homogenized mixtures then were pressed into bricks in a special steel mold (Φ5.0 cm × h3.5 cm) under a pressure of 5–25 MPa. Afterwards, the obtained bricks were transferred to an oven and were dried at a temperature of 100 °C in ambient conditions for 12 h. Subsequently, the dried brick samples were fired in a laboratory type electrical furnace at a temperature range of 1100–1200 °C with a heating rate of 4 °C/min. After firing at the desired temperature for 30 min, bricks were cooled to room temperature by natural convection inside the laboratory electrical furnace. Cylindrical bodies of Φ5.0 cm × h3.5 cm were pressed for water permeability tests. The detailed preparation process is shown in Fig. 1a. Variations were made of parameters in the production process in Table 2 to achieve the best sample performance.

2.2. Characterization

A porosity test was implemented to gain information on the basic properties of the permeable brick. TCLP leaching experiments, water permeability tests and compressive strength tests were done to assess the feasibility of preparing permeable bricks by using all debris.

The dredged mud leaching test was carried out according to the Taiwan EPA standard [12] testing method for solid waste. Dredged

Table 1
The chemical composition of dredged mud, waste glass and discarded porcelain (%).

Chemical composition	SiO_2	Al_2O_3	K_2O	Na_2O	MgO	Fe_2O_3	CaO	TiO_2	Total	LOI
Discarded porcelain	68	22.87	3.13	1.46	1.11	1.63	0.73	0.21	99.23	0.35
Dredged mud	61.12	21.19	4.76	0.2	0	4.76	0.58	0.84	93.530	8.09
Waste glass	71.64	0	0.28	10.6	3.67	0.2	7.88	0	94.27	4.27